4. SITE SELECTION

Because the motion of the ground induces earthquake lateral forces in buildings, it is desirable, but not always possible, to build on sites located on stable and solid geologic formations. Deep and unbroken rock formations, referred to as bedrock, generally will minimize earthquake damage. It is not always possible to restrict the location of buildings to such geologically stable sites. However, by adhering to good construction practices such as those illustrated in this Guide, earthquake resistive houses can be built on other more commonly encountered site conditions.

Houses built on unstable, questionable terrain may by vulnerable to damage due to ground failure as well as earthquake shaking in any seismic risk area. Greater care is required in high and moderate seismic risk areas subject to frequent and/or strong earthquakes, especially where unusual ground conditions have previously caused damage to buildings during an earthquake. The principal hazards are landsliding, liquefaction, settlement or subsidence, and surface fault rupture.

<u>Landsliding</u>

Landsliding is a potential hazard on hillside sites. A landslide scarp is shown in Figure 21 and damage to houses due to landsliding is shown in Figure 25 on page 15. Landslide-prone hillside sites include those that are underlain by previous landslides and those that, while presently stable, are located in unstable geologic formations. Landsliding is a particular hazard where poorly compacted fill has been placed on a hillside slope. Landsliding may cause damage in the absence of earthquake shaking and should be of concern even in low seismic risk areas.

Rockfalls or falling boulders are hazards that are similar to landsliding. If an unstable rock slope is present above a dwelling, boulders could be dislodged by earthquake shaking and impact the dwelling below.

Stable hillside sites with slopes of three to one (3:1) or less are generally satisfactory providing there is no previous history of landslide or movement on similar slopes in the vicinity and the slope does not contain poorly compacted fill. Any hillside site for which a professional soil consultant has made a favorable evaluation of the slope or designed the slopes to be stable can be usually regarded as satisfactory.

Figure 21

Compacted fills placed on slopes with engineering design and control during construction may also be regarded as stable. See Figure 23. For steep sites, geotechnical and engineering assistance is recommended in all seismic risk areas.

Liquefaction

Liquefaction is a phenomenon where loose saturated sandy soil loses bearing capacity and becomes like quicksand during earthquake shaking. The soil can spread laterally or may lose the ability to provide support for building foundations. Young alluvial deposits near rivers, lakes, or bays, or reclaimed land formed by placing uncompacted fills in lakes or bays are most likely to exhibit liquefaction potential.

Settlement

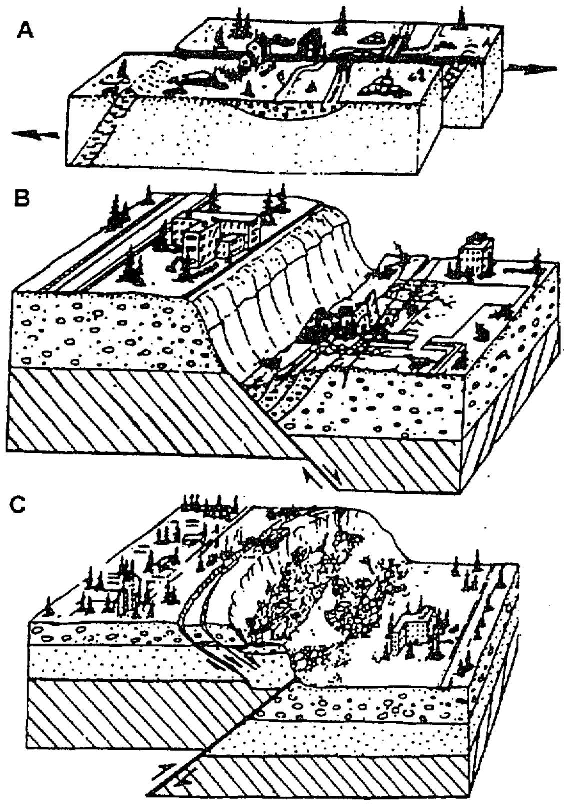
Any site on which fill has been placed without professional control should be regarded as suspect and possibly subject to either long term or earthquake induced settlement or subsidence. Settlement may be most pronounced in high seismic risk areas. The potential for settlement should be carefully evaluated, however, even in low seismic risk areas.

Surface Fault Rupture

Dwellings should not be located directly on an active earthquake fault due to the possibility of surface fault rupture and abrupt shearing displacement occurring along the fault during an earthquake. To avoid construction directly on a fault, a zone of at least 100 feet (50 feet on either side of the fault) where no construction is allowed should be observed. In the event of a large or moderate earthquake a dwelling situated directly on an active fault or in a fault zone would be subject to severe damage even if it was well constructed. Figures 22 and 25 illustrate the types of displacement that can occur along earthquake faults. Damage to two houses that were situated on faults during two different earthquakes are shown in Figure 26.

Site Evaluation

Before selecting a building site, the builder should investigate the existence of any known or recognized geotechnical or geologic hazards discussed above. Maps are available for some locales from the US Geological Survey (USGS), state geologic agencies or from county and city agencies that show locations of active earthquake faults, fault zones and areas of potential landsliding and liquefaction. Some local jurisdictions have used these maps to delineate special zones where residential construction could be vulnerable to damage in the event of an earthquake.



Schematic Diagrams of Surface Fault Displacement. A) Strike Slip. B) Normal Slip. C) Reverse Slip

Figure 22

In areas suspected of being exposed to geotechnical hazards, maps or information indicating such conditions should be sought. A professional consultant may be retained to make a site-specific assessment if a hazardous condition is known or suspected to exist at a site. Construction in areas of low seismic risk may not justify an extensive investigation.

When site conditions are unstable or of questionable soundness, such sites should be evaluated by a professional consultant. If a hazardous condition exists, the site may still be suitable if special measures are taken for the site and/or for the construction of the dwelling. If the site conditions can be sufficiently improved, an earthquake resistive house can be built using the information and illustrations shown in the guide.

Summary

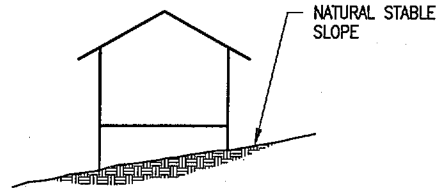
The following summary lists Qualified and Disqualified (hazardous) building sites. Qualified sites are stable sites for which the building details in this Guide are applicable. Disqualified sites require further evaluation as discussed above. Some of these types of sites are shown in Figures 23 and 24.

Qualified Sites For Which Guide is Applicable

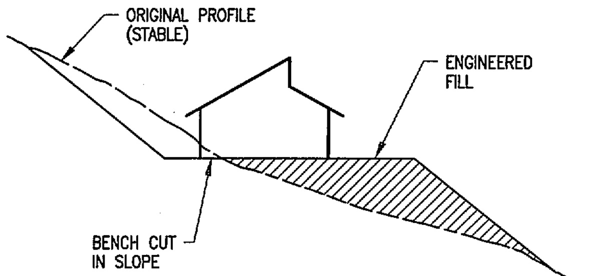
1. Stable and solid geologic formations – bedrock
2. Firm, stable soil deposits
3. Stable hillside slopes
4. Engineered land fill placed over stable soils
5. Sites recommended by a professional soil consultant.

Disqualified (Hazardous) Sites Requiring Further Evaluation

1. Sites built on non-engineered fill
2. Sites prone to landsliding or rockfalls
3. Reclaimed waterlands, marshes, or alluvial soil sites having a potential for liquefaction.
4. Sites directly over an active fault or within a 100 feet wide zone, i.e., 50 feet either side of the fault.



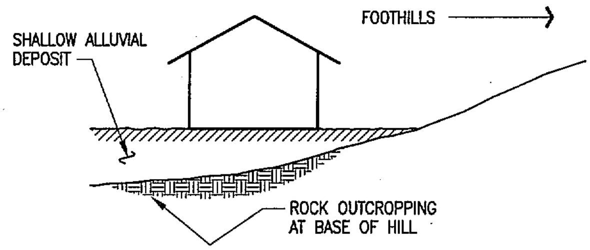
MODERATE SLOPE



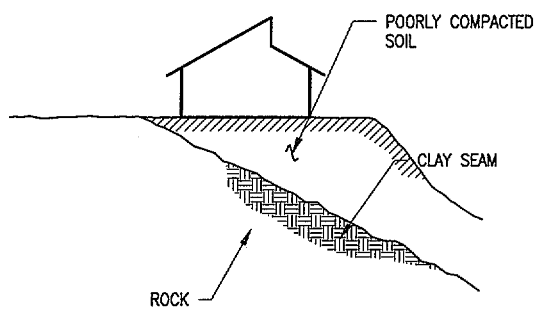
STEEP SLOPE

QUALIFIED

Figure 23



UNCONSOLIDATED FILL



UNSTABLE SLOPE

DISQUALIFIED

Figure 24

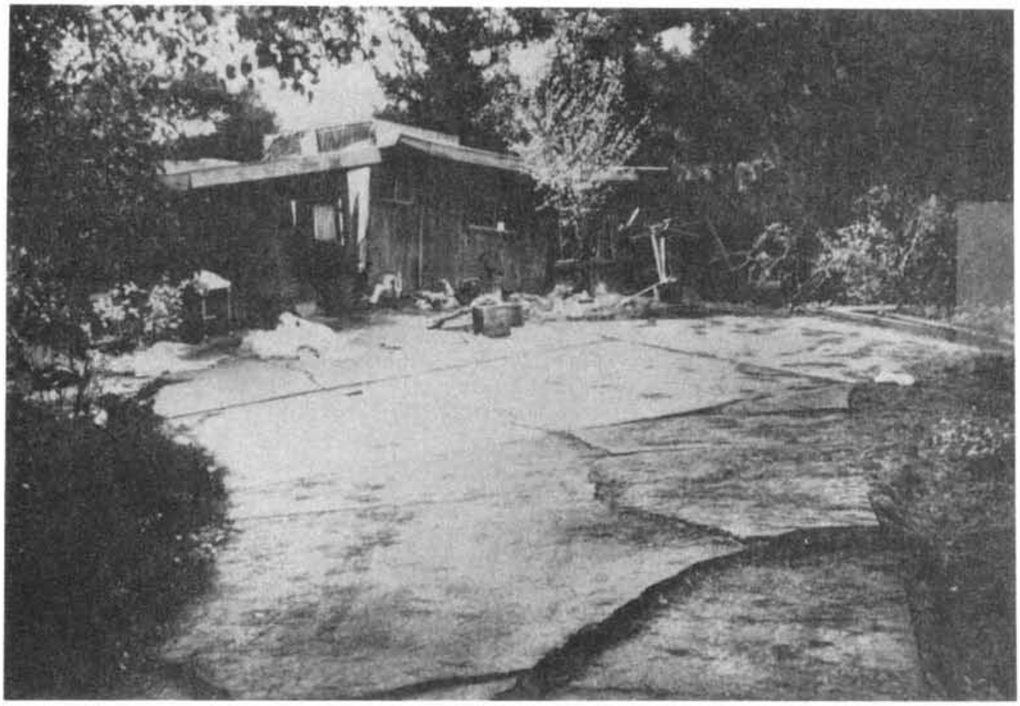


Figure 25

Figure 26

5. ELEMENTS OF THE SEISMIC RESISTANCE SYSTEM

This section identifies and describes the components of residential construction that resist earthquake forces. The text and illustrations show how a complete, uninterrupted and well defined load path is constructed. It is essential that all of the seismic resisting components be tied together to form an earthquake resisting system without weak links. Connections between the resisting elements provide the continuity necessary to assure an uninterrupted path. The three principal elements of the system are the floor and roof diaphragms, shear walls and the foundation. See Figure 27.

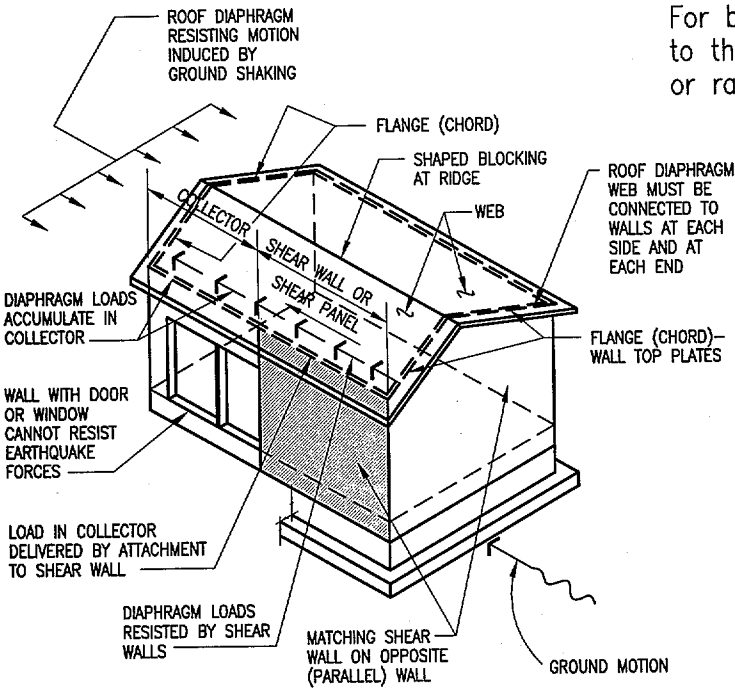


Figure 27

The function of the floor and roof diaphragms is to transfer earthquake forces to shear walls which are usually located at the exterior of the building. For wood framed houses, diaphragm framing usually consists of the floor or roof sheathing, joists or rafters, blocking at the ends of joists or rafters and wall top plates. Cold formed steel framed houses are framed in essentially the same manner.

Wood Structural Panel is always acceptable for roof and floor sheathing. Diagonal sheathing, although not commonly used, but still permitted by Code, can be used instead although not as effectively. Straight sheathing may be used in areas of low seismic risk but should be avoided in high and moderate seismic risk areas. Spaced roof sheathing, often used for shingled roofs, is not recommended but may be used in low seismic risk areas where wind loads are also low.

For best performance, sheathing should be applied to the framing with face grain across the joists or rafters and with nailing on all edges and at intermediate supports. See Figure 17 on page 7. Each sheet must be nailed along each short edge to a framing member. Abutting short edges of adjoining sheets must be nailed to the same (mutual) framing member. The long edge of the sheet may be nailed to blocking inserted between the joists or rafters with abutting edges nailed to the same member. Blocking of edges to resist lateral forces is not usually required for roof or floor diaphragms in residential construction, but can be used to increase the stiffness and strength of the diaphragm. Where tongue and groove sheets are used, blocking may be omitted along the long edges. A bead of construction adhesive should be used on the top edge of floor joists. This is usually done to prevent squeaking but tests have shown that it also increases stiffness and improves performance. Adhesive on roof framing members can be used to stiffen the roof diaphragm.

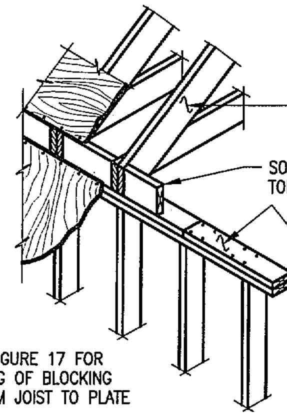
Edge of sheet nailing of floor and roof sheathing is required at diaphragm boundaries, along exterior wall plate lines and along interior walls used as shear walls. Sheathing is usually edge nailed to blocking or rim joists or similar members attached to the wall top plates. See Figure 17 on page 7.

Nailing of floor and roof sheathing prescribed in building codes for conventional construction is ordinarily adequate for diaphragm strength.

Exterior wall top plates function as flanges or chords for the diaphragm and resist the tension and compression resulting from beam action. The wall double top plates at the boundaries of the diaphragms must be spliced along the widths and lengths (perimeter) of the diaphragms in order for them to be "continuous". See Figure 28.

Because of strength and stiffness limitations, diaphragms are restricted to certain diaphragm ratios of length (L) to width (W). See Table No. 3 on page 39. If the horizontal distance (span) between exterior walls is too large, the diaphragm becomes long and narrow and consequently too flexible. The diaphragm ratio (L/W) is important because excessive deflection of the diaphragm may cause wall damage and glass breakage. If the distance between exterior walls is too great, the proper diaphragm ratio may be achieved by using interior shear walls parallel to the exterior walls to reduce the diaphragm span.

The primary vertical resisting elements are the shear walls that support the floor and roof diaphragms and resist earthquake forces generated in the diaphragms. See Figure 11 on page 6. Aspect ratios of shear walls (vertical diaphragms) are established to control drift. The recommended height (H) to width (W) ratios shown in Table 3 on page 39, should not be exceeded and spacing of shear walls should be as prescribed in the building code or as shown in this Guide.



TOP PLATE SPLICE

Figure 28

Shear wall framing usually consists of wall top plates, studs, sheathing, floor sill plate, hold-downs and other connections. Top plates should be doubled, lapped and spliced for continuity. Studs should be doubled at the ends of shear walls and internailed stud to stud. Sheathing must be nailed to blocking or rim joists attached to the wall top plates, to the end or corner studs, and to the floor plate or sill. The floor sill plates must be bolted to the foundation or otherwise attached by special hardware designed to substitute for bolts.

Several sheathing materials are available with Wood Structural Panel sheathing being the most effective. See Table No. 3 on page 39. It is important to use Wood Structural Panel sheathing in high seismic risk areas.

Gypsum board wall sheathing applied to the studs can also be used to resist earthquakes. See Table No. 3 on page 39. As demonstrated in the Northridge and other earthquakes, when gypsum board is used for shear wall sheathing in high seismic risk areas severe damage can result from strong earthquake shaking. Gypsum board is usually adequate as sheathing on shear walls in moderate and low seismic risk areas. Gypsum board may be applied to the walls with long edges vertical or horizontal. But if long edges are horizontal they should be blocked.

Stucco over wire lath applied directly to the studs can be used for seismic resistance in all seismic risk areas, although, it is not advised in high seismic risk areas. The lath must be securely nailed to the studs, wall top plates and sill. In high seismic risk areas, stucco can be vulnerable to severe cracking as demonstrated in the Northridge and other earthquakes.

Let-in bracing provides only minimal seismic resistance and should not be relied on except in low seismic risk areas where wind loads are also low.

For shear walls to be effective in resisting the diaphragm loads and controlling damage they should have height to width ratios in high and moderate seismic risk areas of 2:1 or less. See Figure 29. A larger ratio may be allowed by certain codes, but experience in earthquakes has demonstrated that limiting height to width ratios will improve performance. Shear walls, in two story construction need only satisfy this ratio in each story although better performance can be achieved by computing the ratio using the full height of the wall. A minimum width of 4'-0" for shear walls in high and moderate seismic risk areas is advised.

As noted before, earthquake forces must be transferred from the roof diaphragm into the shear walls and through the walls to the ground at the foundations. At the interface of the horizontal diaphragms and shear walls, the roof and/or floor sheathing is nailed to the top of solid blocking or rim joists, and the wall sheathing is usually nailed to the vertical face of the same block or rim joists. Where the wall sheathing only extends to the top of the top plates, the blocking or rim joist must be securely nailed or connected to the top plates. See Figure 30 and Figure 32.

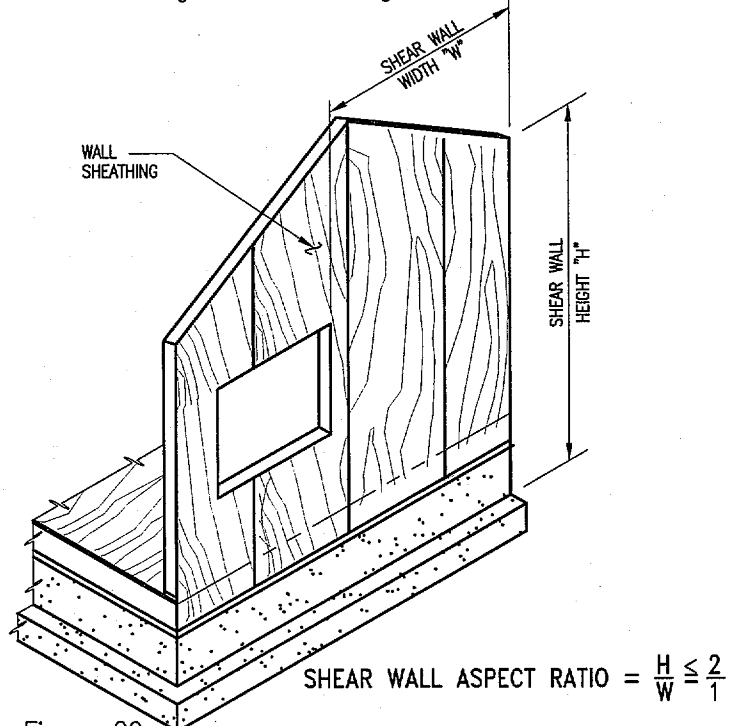
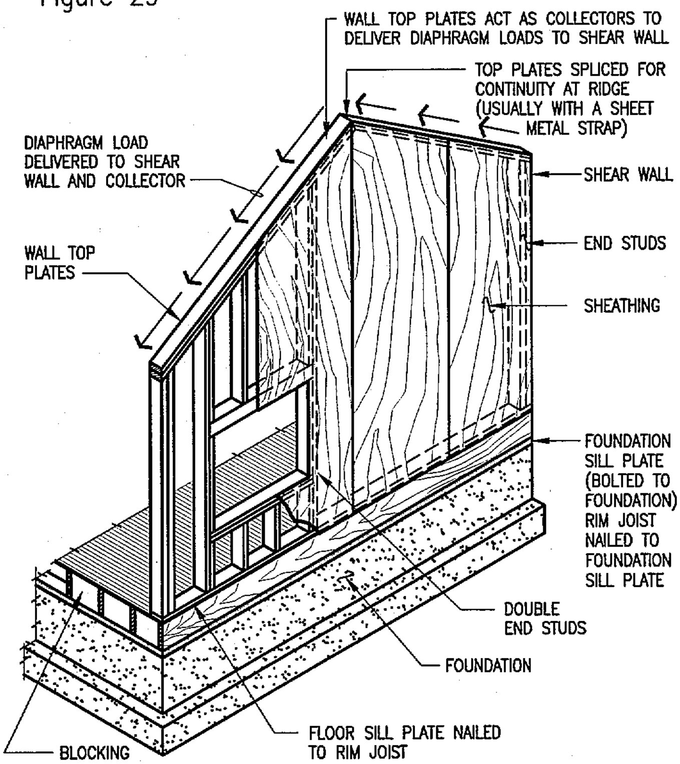


Figure 29



END SHEAR WALL

Figure 30

Wall top plates act as flanges and collectors for the roof and floor diaphragms and can be loaded in tension or compression. Top plates must be spliced for continuity. Wall top plates are stabilized against buckling by nailing the joists or rafters to the plates or by means of a rim joist or end rafter where the framing runs parallel to the wall. Corner and/or end studs act as flanges for shear walls and carry tensile or compressive forces. Only full length studs may be used as flanges and the wall sheathing must be edge nailed to the end studs rather than to adjacent studs. See Figure 31.

Because of the tendency of a tall, narrow shear wall to overturn, a wall with insufficient weight may uplift from the foundation at either end of the wall. To prevent this, the corner or end studs can be anchored to the footing with a hold-down device. See Figure 31 here and Figure 55 on page 29. Experience has shown that hold-down bolts must be inserted in correctly sized holes and must be tight. Bolts should be retightened before closing in the walls. Better performance can be obtained by using 1/4" diameter wood screws to connect the hold-down to the post.

To prevent the building from sliding off of its foundation when exposed to earthquake shaking, the sills must be bolted to the footings. See Figure 33. The footings will then transfer the earthquake loads back to the ground. Bolts should be set accurately on the center line of the sills. A consistent spacing of the bolts should be maintained. Improperly installed sill anchor bolts have contributed to damage in past earthquakes. Care should be taken not to oversize the holes in the sills and the bolts should be tight with a washer under the nut for firm bearing. Use plate washers in high seismic risk areas. Anchor bolts should not be countersunk in the sill. Floor and wall sheathing must be nailed to the framing. See Figures 32 and 33.

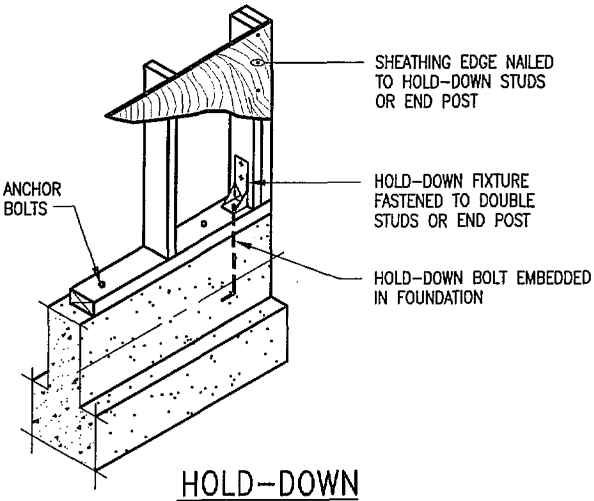


Figure 31

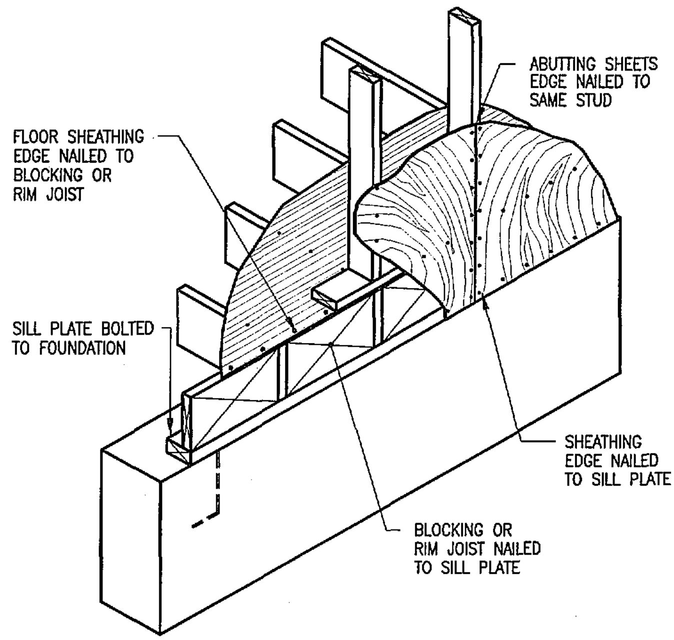


Figure 32

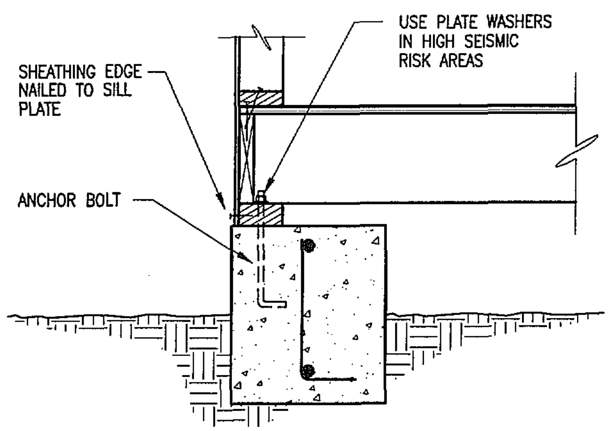


Figure 33

6. FOUNDATIONS AND FOUNDATION DETAILS

Footing types are dictated by the underlying ground conditions and by their inherent ability to resist forces caused by earthquakes. Some consistent rules apply and should be followed regardless of the footing type selected.

To avoid damage from unequal settlement and subsidence, foundations should be on uniform ground conditions, i.e., footings for the same building should not be part on rock and part on loose fill, soft soil or other significantly different ground conditions unless specially designed to accommodate the non-uniform conditions See Figure 34.

Builders should investigate building sites for ground conditions that could have an unfavorable impact on the foundation. Information noted in Section 4, SITE SELECTION, in the Guide indicates the minimum satisfactory conditions for constructing foundations to resist earthquakes. Local building codes generally provide information regarding minimum standards for foundations. Supplemental information intended for earthquake resistance is contained in the Guide.

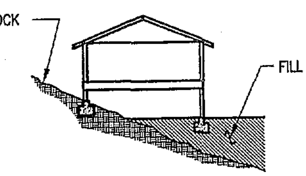
Underground basement walls must support the weight of the structure above, floor and roof loads, earth pressures and earthquake loads perpendicular to the plane of the wall. Basement walls acting as shear walls may be thought of as a continuation of the shear wall above and resist the earthquake forces transmitted to these shear walls by the horizontal floor diaphragms, See Figure 35.

Sill plates on basement walls, when properly anchored, keep the shear walls above from sliding or moving. The minimum bolting requirement for moderate and low seismic risk areas is 1/2" diameter by 10" long bolts spaced a maximum of 6'-0" on center with 7" of embedment.

For high seismic risk areas bolts should be 5/8" diameter by 10" long spaced at 4'-0" maximum with 7" of embedment. Bolts should be centered on the sill plate.

Sill plates are normally 2x material, but in areas of high seismic risk, 3x sill plates provide better protection from splitting. Avoid countersunk washers and nuts in sill plates. In areas of high risk, sill bolts should have plate washers under the nuts. Use 3" x 3" x 1/4" plate washers for 1/2" and 5/8" bolts and 3" x 3" x 3/8" plate washers for 3/4" bolts. At ends of sill plates, bolts should be placed 9" from each end of each piece.

Local building codes should be consulted for reinforcing requirements for basement walls. Reinforcement necessary to resist earth pressure and gravity load will usually be adequate for earthquake resistance.



NON-UNIFORM CONDITION

Figure 34

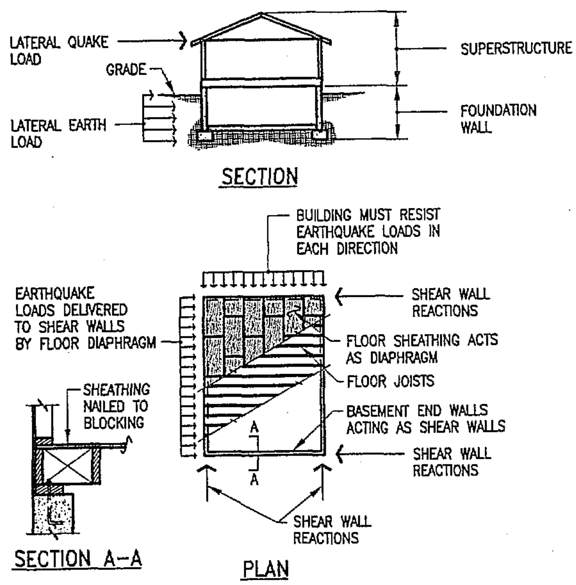


Figure 35

Basement or foundation walls supporting a framed floor where there is a difference in elevation from the top of the walls to the underside of the floor joists may have cripple stud walls supporting the framing. See Figure 36. Cripple stud walls are vulnerable to earthquake shaking and must be braced or sheathed as appropriate for all seismic risk areas. Wall bracing or sheathing for cripple walls should conform to the same requirements as for full height shear walls and can be of any material proposed in this Guide. Plywood or oriented strand board is recommended for high seismic risk areas. Gypsum board sheathing and/or stucco can be used for moderate and low seismic risk areas. Let-in bracing is not recommended for cripple walls except that it may be used in low seismic risk areas.

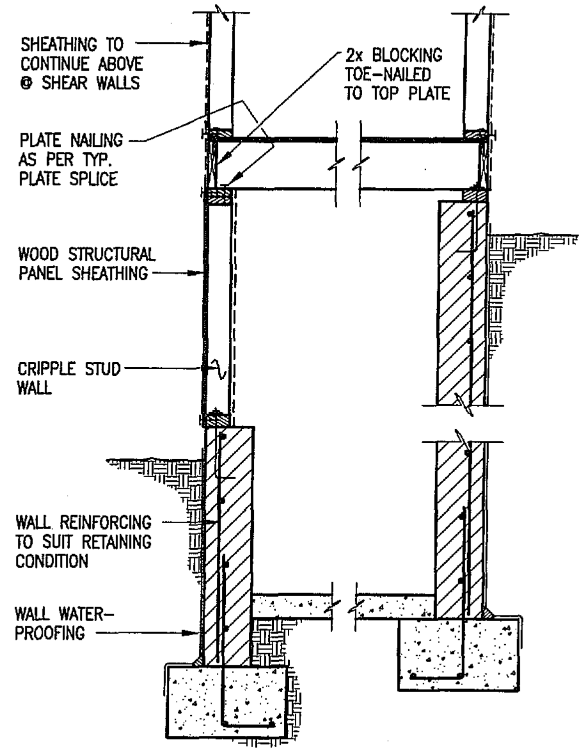


Figure 36

As observed in the Northridge Earthquake, cripple stud shear walls supported on stepped footings along steeply sloping sites performed poorly. They should not be used in high seismic risk areas. Except for high walls, a concrete stem wall above the footing should continue to the floor framing, thus eliminating the need for a cripple wall.

Continuous perimeter footings are suitable for ground conditions consisting of firm natural sites, engineered landfills and moderate stable slopes. Concrete footings are usually placed in trenches without forms with the bottom of footing at a minimum depth required by code or at least 12" below adjacent grade. Wall sill plates can rest directly on the tops of footings if the footings are high enough relative to the adjacent grade. If a grade beam does not project above the ground, a concrete or masonry stem wall resting on it can be provided. Vent openings and crawl holes may be placed in the stem wall, but the grade beam should be continuous without interruption.

In areas of high seismic risk, footings should have reinforcing. See Figures 37 and 38. Reinforcing is recommended as shown in moderate seismic risk areas, but reinforcing may be omitted in low seismic risk areas if codes and local construction practices permit.

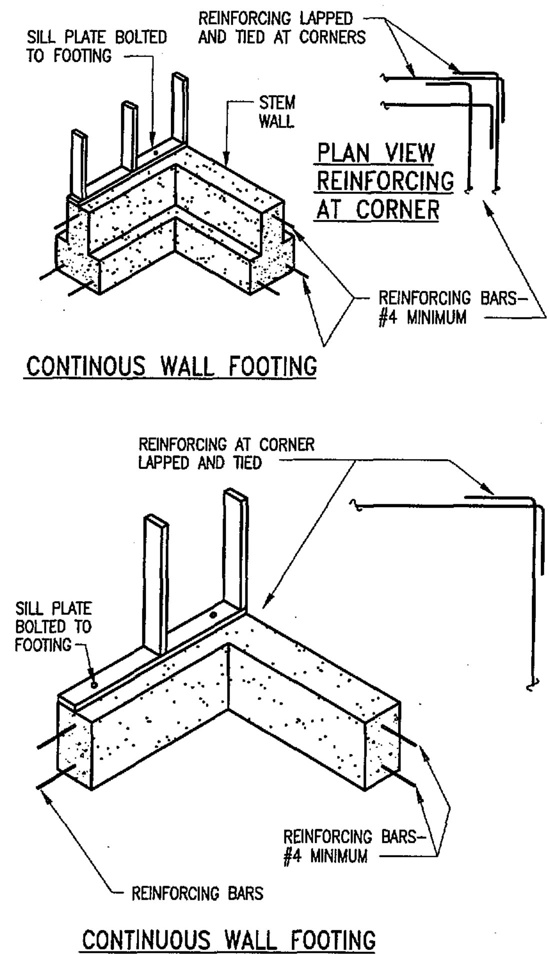


Figure 37

To be effective, reinforcing must be lapped at splices and well tied together at the corners and intersections. Where placed separately, stem walls and grade beams should be doweled together. Sill plates must be bolted to the tops of grade beams or stem walls. See Figure 39. The spacing and size of bolts should be as described for basement walls. Hold–down anchor bolts must be embedded in the grade beams as shown in hardware manufacturers' catalogs.

Interior bearing walls or partitions used as shear walls should have continuous footings similar to perimeter foundations. See Figure 38. Reinforcing, where used in footings under interior walls, should be lapped with reinforcing in the perimeter footings at their intersections.

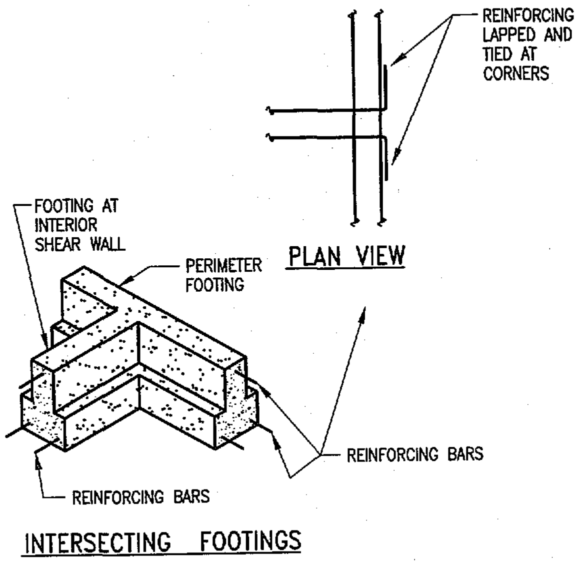


Figure 38

Often, stud walls are prefabricated on the ground and lifted into place. In such cases, bolts holes in the sills should not be oversized to accommodate the preset bolts in the footings. Bolt holes should be marked and drilled in the sill plate using a template made from the known location of the bolts projecting from the footing. After locating and drilling the bolt holes in the sill, the wall can be lifted and set over the anchor bolts.

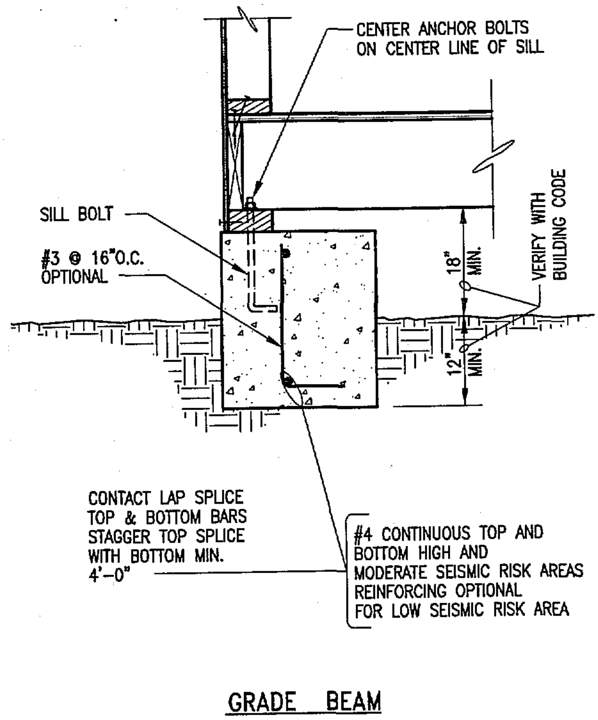
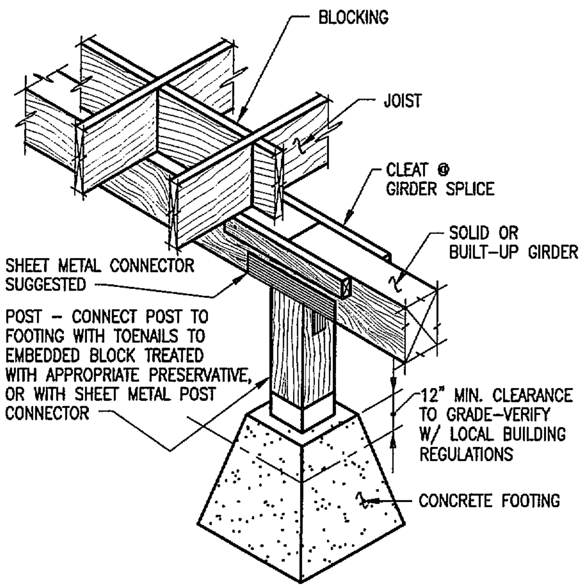


Figure 39

Floor joists supported on interior bearing lines other than shear walls can be supported on beam and girder framing systems attached to posts bearing on individual spread footings or precast piers. See Figure 40. Sheet metal post caps should be used to connect beams/girders to the posts. If a beam/girder acts as a collector for a shear wall, it must be spliced for continuity with wood cleats or metal straps. Splices should occur only over posts. Girders should be in lengths as long as possible to minimize splices.



INTERIOR BEARING LINE

Figure 40

Slab–on–grade foundations have performed well in earthquakes. Slab–on–grade construction is a suitable foundation system for most sub–grade conditions. When highly expansive soil or clay soil is encountered, a geotechnical engineer should be consulted. Slabs–on–grade may be used on flat sites and are ideal for homes framed of wood or cold–formed steel with no basement or crawl space. Slabs, unless they are 12" or more in thickness, should have thickened edges at exterior bearing walls and integral thickened trenched footings for interior bearing walls and shear walls. See Figures 41, 42 and 43. Sills must be bolted to the slab with bolt sizes and spacing as previously described for continuous wall footings.

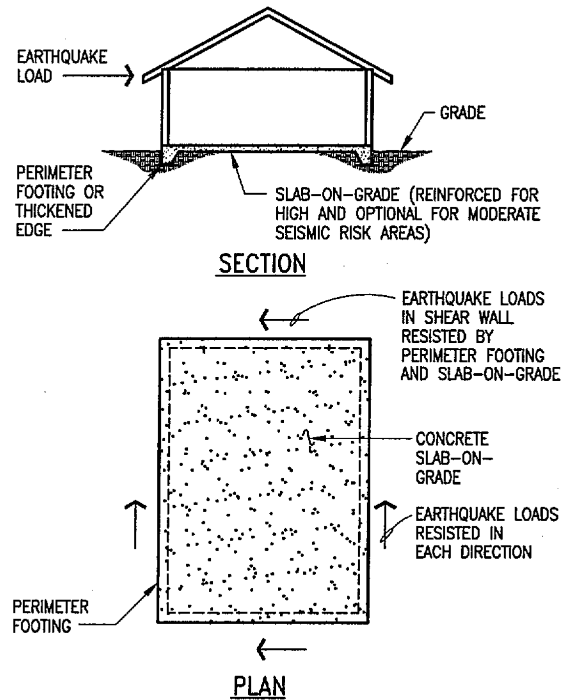


Figure 41

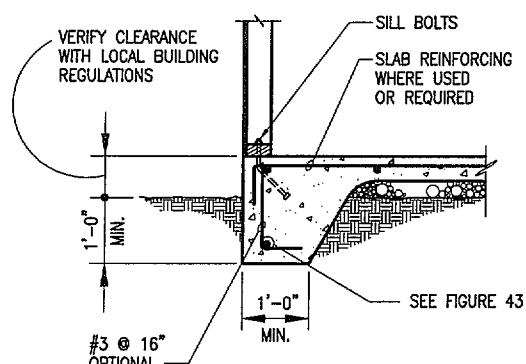
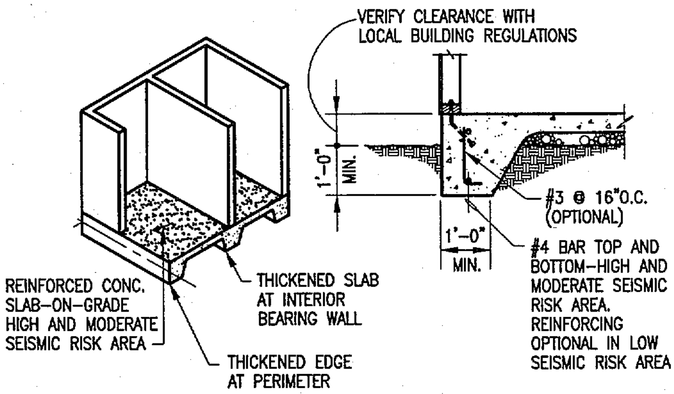


Figure 42



CONCRETE SLAB-ON-GRADE

Figure 43

The slab floor will act as a diaphragm and should have minimum reinforcing in high seismic risk areas so that cracks and differential displacements do not impair the diaphragm properties. Slab reinforcing is also effective in bridging across soft spots and depressions in the subgrade regardless of need for seismic resistance. Reinforcing is optional in low seismic risk areas. At a minimum, welded wire fabric is recommended to keep slabs integral and minimize cracking.

Drilled-in-place concrete-filled piers with grade beams spanning between the piers are suitable for compressible soils, loose land fills, and known weak soil conditions. Sizes and depths of piers must be determined from local building regulations or from a geotechnical consultant. Reinforcing of the grade beams must be provided to support the weight of the building and contents. Reinforcing required for normal loading will be adequate for earthquake loads as well. Reinforcing should employ individual bar lengths as long as practical and be lapped and tied at splices and at corners and intersections. The piers should be doweled to the grade beams. See Figure 44.

Some foundation types are not suitable for seismic resistance without special consideration related to either the site or special requirements of the building.

See Table No. 2 on page 26. Four conditions not covered in the Guide are listed below:

1. Pole houses.
2. Houses on pile supported platforms.
3. Floating foundations on unengineered hydraulically placed landfill.
4. Isolated footings not connected by continuous grade beams

Information and details of construction shown in the Guide may not be universally suited to these foundation types. Construction should not be attempted without the assistance of a design professional.

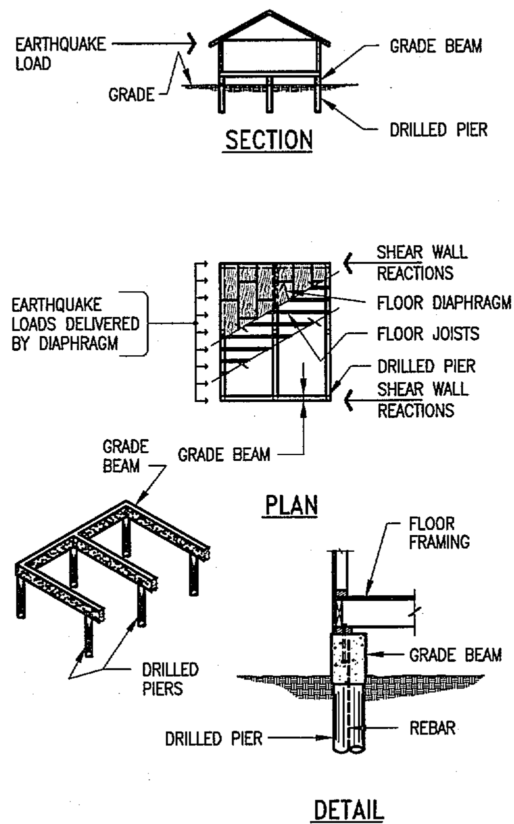
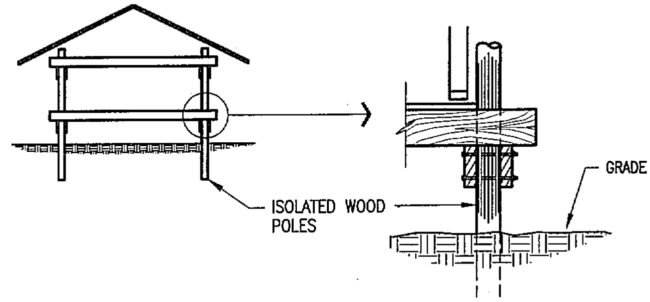
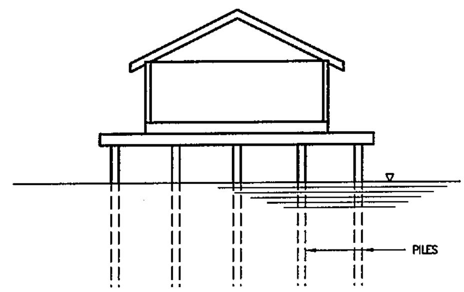
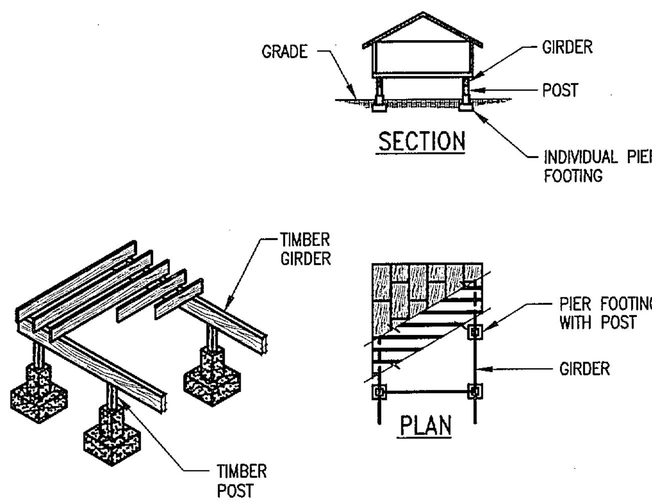


Figure 44

Table No. 2 – Foundation Types Requiring Special Construction	
Pole House	
Pile Supported Platform	
Individual Isolated Piers	
Floating Foundation on an Unengineered Landfill